Wisconsin Highway Research Program

Field Study of Air Content Stability in the Slipform Paving Process

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Wisconsin Highway Research Program

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SECTION 2. SUMMARY PAGE

Project Title	*Field Study of Air Content Stability in the Slipform Paving Process*
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Proposal Date	March 3, 2010 (Revised October 11, 2010)
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Proposed Contract Period	18 months
Total Contract Amount	$79,999
Indirect Cost Portion at 185%*	$19,147

*APTech indirect costs (overhead and fringe benefits), which are computed as 185% of APTech's direct labor costs.

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SECTION 4. RESEARCH PLAN

Background

A number of factors are known to affect the air content of paving concrete, including such items as portland cement type and content, supplementary cementitious materials type and content, admixtures, placement methods, ambient temperatures, and so on. In addition, some of the air that is present when the concrete is placed in front of the paver is lost as it is vibrated and consolidated through the slipform paver.[1, 2] Recognizing this, a number of state highway agencies (SHAs) now specify that concrete either be sampled after the paver (e.g. Kansas, Indiana) or that the air content of concrete placed on grade in front of the paver be higher than that normally required to ensure the freeze-thaw durability of the concrete (e.g., Wisconsin, Iowa). In the case of the Wisconsin Department of Transportation (WisDOT), the target air content for concrete on grade in front of the paver is 5.5 to 8.5 percent, with the assumption that approximately 1 percent of the air will be lost as it is vibrated and consolidated by the paver. This issue is of increasing importance as WisDOT moves to adopt performance-related specifications as there is a need to select the "correct" amount of air necessary to ensure resistance to freeze-thaw damage while also not compromising the strength and permeability of the hardened concrete.

The need for entrained air in concrete is based on decades of research that began in the 1930s. The microscopic air bubbles that are purposefully entrained in concrete are essential to protect it against freeze-thaw damage, acting as tiny pressure relief valves that dissipate stress as saturated concrete freezes. As a result, air entrained concrete is universally specified for road construction throughout most of the country including the upper Midwest (e.g. Wisconsin, Michigan, Minnesota, Iowa, and so on).

Conceptually, the mechanism leading to freeze-thaw damage in concrete is quite simple, resulting from the 9 percent volume expansion that occurs as water in small capillary pores transitions from liquid to solid. In this theory, the hydraulic pressure generated in the remaining liquid water can fracture the surrounding concrete unless it is relieved. But research has shown that the actual mechanism is much more complicated, involving the generation of osmotic pressures that develop as the ionic concentration of the pore solution changes as ice forms. Many chemical deicers tend to amplify that mechanism and also create thermal shock. Other theories on why damage occurs abound but regardless of the exact mechanism, it is clear that a minimum volumetric content of air must be entrained in the concrete and the bubbles must be close enough to one another to protect the paste from damage during freezing.

Based on this knowledge, modern concrete practices dictate that under severe freezing and thawing conditions where the concrete will be subjected to chemical deicers, the target amount of total air should be between 5.5 and 7.5 percent, depending on the size of the coarse aggregate.[3] For the entrained air to be effective, it must be present in relatively small bubbles that are closely spaced. Powers developed an expression called the spacing factor that describes, for the majority of the paste, the distance to the nearest air void.[4] Typically, the entrained air bubbles should range in size from 50 to 200 μm[5] and the spacing factor should be less than 0.200 mm (0.008 in) to be effective in protecting the hydrated cement paste from freeze-thaw damage.[3] However, if excessive air is entrained in the concrete, there is a commensurate loss of strength and an increase in permeability, both of which negatively affect the durability of the concrete.

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[1] Whiting, D. and M. Nagi. 1998. *Manual on Control of Air Content in Concrete.* EB 116. Portland Cement Association, Skokie, IL.

[2] Taylor et al. 2007. *Integrated Materials and Construction Practices for Concrete Pavement.* HIF-07-004. Federal Highway Administration, Washington, DC.

[3] American Concrete Institute. 2008. *Guide to Durable Concrete*. ACI 201.2R-08. American Concrete Institute, Farmington Hills, MI.

[4] Snyder, K., K. Natesaiyer, and K. Hover. 2001. "The Stereological and Statistical Properties of Entrained Air-Voids in Concrete: A Mathematical Basis for Air-Void System Characterization." *Materials Science in Concrete VI*, American Ceramic Society, Westerville, OH.

[5] Mehta, P. and P. Monteiro. 2005. *Concrete: Microstructure, Properties, and Materials.* McGraw-Hill Publishing, New York, NY.

Although considerable research has been conducted on air-entrained concrete, a number of factors remain unresolved. First of all, most information regarding the influence of the entrained air-void system on freeze-thaw damage is based solely on the use of vinsol resin-based air entraining admixtures (AEA), as these were most commonly used in the past. Today, the use of non-vinsol resin AEA (often referred to as synthetic air-entraining admixtures) has increased. Laboratory studies have found that non-vinsol resin AEA produce a finer air-void system that is less likely to be affected by vibration, speculating whether it might be possible to maintain freeze-thaw durability at a lower overall air content.[6, 7] Relevant research on the impact of various types of AEA on the air-void system must be reviewed, particularly in cases where the use of non-vinsol resin AEA was implicated in creating excess air along aggregate interfaces, resulting in poor strength. Similarly, relevant research on the air-void system created by various types of AEA (particularly with regards to coalescence of air bubbles and poor strength where non-vinsol resin AEA was used) must be examined.[8]

It is also well known that the air-void system is created through the action of the concrete mixer, which "traps" the air in the mix through the use of the AEA. Although mixing time is a recognized factor, little is published on the impact of different types of concrete plants. Furthermore, air loss and the potential disruption of the air-void system by internal vibration and/or manipulation of the finished surface as the concrete is paved are also possible. Often problems associated with this are attributed to the concrete itself and not specifically to the paver used, although the frequency of internal vibration is of concern.[9, 10] The creation of "vibrator trails" in slipform concrete is one artifact of air loss (as well as mix segregation) caused by internal vibration. Another is the loss of air at the surface, although this is rare in slipform paving unless additional finishing is applied. Nevertheless, the impact of specific concrete plants or pavers on the in-place concrete air-void system is rarely studied unless something has gone wrong.

As WisDOT moves towards the adoption of performance-related specifications, the influence of these variables need to be quantified, and if necessary, recommendations for changes to current values for concrete properties need to be made.

Objective

As stated in the RFP, the objective of this study is to "evaluate the impacts to the air void structure and content due to the vibration and consolidation action of today's modern slipform pavers used in Wisconsin." It is the intent to quantify the air content and unit weight of the fresh concrete before and after it has gone through the slipform paver. The air-void system parameters in hardened concrete will then be assessed using cast and extracted specimens. Knowing what changes occur to the air content and air-void system parameters will help identify appropriate air content target values, thereby allowing WisDOT and the Wisconsin paving industry to optimize the properties of the mix to ensure the in-place concrete meets or exceeds desired properties.

Research Approach

This section describes Applied Pavement Technology's (APTech's) proposed approach to conduct this project. APTech, under the direction of Dr. Tom Van Dam as Principal Investigator, will serve as the prime contractor and will be assisted in this project by two subcontractors: Michigan Tech University

[6] Sutter, L., T Van Dam., and M. Thomas. 2007. *Evaluation of Methods for Characterizing Air Void Systems in Wisconsin Paving Concrete.* WHRP-07-05. Wisconsin Department of Transportation, Madison, WI.

[7] Tanesi, J. and R. Meininger. 2006. *Freeze-Thaw Resistance of Concrete With Marginal Air Content.* FHWA-HRT-06-117. Federal Highway Administration, McLean, VA.

[8] Cross. W., E. Duke, J. Keller, and D. Johnston. 2000. *Investigation of Low Compressive Strengths of Concrete Paving, Precast, and Structural Concrete.* SD98-03-F. South Dakota Department of Transportation, Pierre, SD.

[9] Stutzman, P. 1999. *Deterioration of Iowa Highway Concrete Pavements: A Petrographic Study.* NISTIR 6399. National Institute of Standards and Technology, Gaithersburg, MD.

[10] Taylor et al. 2007. *Integrated Materials and Construction Practices for Concrete Pavement.* FHWA Publication No. HIF-07-004. Federal Highway Administration, Washington, DC.

(MTU, who will conduct the laboratory testing and analysis) and American Engineering Testing, Inc. (AET, who will assist in the field data collection).

Work Plan/Experimental Design

Task 1: Comprehensive Literature Review

Under this task, the research team will conduct a thorough search of available literature focusing on air content, air entrainment, air content testing, and loss of air and changes in the entrained air-void system as a result of the slipform paving process. The search will focus on research done in the last 10 years. The literature search will begin with an internal search of the APTech extensive transportation library and the personal files of all research team members. The search will then move to the online libraries and publication directories of various highway agencies, industry organizations, and academic institutions. These include:

- TRB/NCHRP (including the Research in Progress [RIP] database).
- American Association of State Highway and Transportation Officials (AASHTO).
- Federal Highway Administration (FHWA) and National Highway Institute (NHI).
- Other national research programs/foundations (such as the Innovative Pavement Research Foundation for the National Concrete Pavement Technology Center).
- Selected state DOTs.
- Concrete pavement industry groups.
- Academic institutions.
- Testing and standards organizations.

In addition, foreign databases, such as the World Road Association (WRA), the Transportation Association of Canada (TAC), the Transport Research Laboratory (TRL), and the Australian Road Research Board (ARRB), will also be searched to assess the international experience.

All pertinent reference materials identified in the literature search will be obtained for detailed review and potential use in the study. The materials will be compiled according to the following technical topic headings:

- Air-Void System Parameters and Freeze-Thaw Durability—Information on key air-void system parameters and how entrained air protects concrete against freeze-thaw damage.
- Air Entraining Admixtures (AEA)—Information on the mechanisms of air entrainment looking at vinsol resins and modern non-vinsol resin based admixtures.
- Assessment of Air Content and Entrained Air-Void System—Information on traditional and emerging test methods for air content of fresh concrete and methods used to assess air-void system parameters in fresh and hardened concrete.
- Factors Affecting Air Content in Field Concrete—Information on the effect of various factors including materials, environmental conditions, and mixing and placement techniques on the amount and quality of air entrained in concrete.
- Air Content and Air-Void System Parameters Before and After the Paver—Information regarding how placement of stiff concrete mixtures using a slipform paver impacts the amount and quality of air in the resulting pavement.

The resulting collection of literature and documentation will be thoroughly reviewed for potential use in this study. This review will focus on the many aspects of ensuring that both the quantity and quality of the air-void system is sufficient to protect the pavement against freeze-thaw deterioration in a harsh climate where deicing chemicals are commonly used. A focus will be placed on both formal and informal documented practices of selected highway agencies located in the midwest to get a better understanding of their approach to ensuring adequate air entrainment in the resulting pavement. This information will help guide the development of the detailed final testing matrix in Task 2.

The research team has performed these types of detailed literature reviews on numerous NCHRP, FHWA, and state studies, and fully understands their importance to the final products of the research. At the end of this task, the project Principal Investigator, Dr. Van Dam, P.E., and Co-Principal Investigator, Mr. Kurt Smith, P.E., will meet with the Technical Oversight Committee (TOC) to discuss the results of the literature review and to discuss the future field testing activities.

Task 2: Develop Detailed Final Testing Matrix

After completion of Task 1 (including the meeting with the TOC), the research team will develop a detailed final testing matrix to be used for the testing of air contents on paving projects as well as guiding the subsequent testing of hardened concrete in the laboratory. The following discussion details the research team's current thinking regarding the testing matrix.

As discussed in the background section of this proposal, it is known that many factors influence the final air content and air-void system parameters of concrete placed with a slipform paver. The air content and the stability of the air-void system is influenced by the materials used (cement, SCMs, chemical admixtures, aggregate grading and texture, and water), mixture properties (*w/cm*, slump), batching (sequencing, mixer type and size, mixing speed and duration), transport (type of truck, time of delivery, agitation, retempering), placement (type of placement), consolidation (type of paver, vibration frequency and duration), finishing (type, timing), and temperature. With this vast number of variables, no single study can be designed to provide statistically valid results that will be universally applicable to all conditions. Instead, the experimental plan proposed for use in this project is designed to make use of the significant amount of information that already exists regarding most of these factors, and then test a representative number of projects to validate WisDOT's current approach to providing air content for freeze-thaw durability.

Based on the RFP, the major variables to be considered are as follows:

- Coarse aggregate type (2): northern glacial gravel and southern crushed limestone.
- Air entraining admixture (at least 2): vinsol resin-based AEA and at least one non-vinsol resin-based AEA.
- Concrete plant (2): Rexcon and Erie-Strayer.
- Paving machines (4): Guntert and Zimmerman (G&Z) S850, Gomaco GHP2800, Gomaco GHP2600, and Rexcon Town and Country.

Conducting a full-factorial experiment would result in a *2x2x2x4* experimental matrix, requiring 32 projects be evaluated. This approach is infeasible for a number of reasons, the most predominant being that the project resources are insufficient to carry out such a broad experiment. A partial factorial experimental design could be employed to reduce the number of required projects to eight or so, but this would be of limited use because the independent variables are not random and there are multiple known and unknown interactions between the variables that will result in confounding of the experimental results. For example, based on the RFP, only Zignego Company is using an Erie-Strayer concrete plant, whereas most others are using a Rexcon plant. Since Zignego is primarily located in the southeastern part of the state, it may be difficult to find a project in the summer of 2011 in which Zignego is operating in the northern part of the state working with northern glacial gravel. Assuming that a difference is observed on a project constructed by Zignego, it would be impossible to tell whether that difference was from the use of the Erie-Strayer concrete plant, the coarse aggregate source, or any number of other variables that are not included in the study. Furthermore, Zignego does not operate a Gomaco paver, but instead a G&Z S850 paver, again resulting in confounding of the results. There are many other similar known and unknown limitations and interrelationships amongst the independent variables (coarse aggregate type, AEA, concrete plant, and paving machine) that prevent the effective application of a statistically derived experimental plan for this project. And this does not even consider the fact that it will be impossible to control other variables that are known to have a large impact on air content and the characteristics of the air-void system, such as cement type and content, fly ash source and content, other chemical admixtures, mixing speed and times, and temperature. Thus, a statistically valid experiment to address all these factors is well outside the scope and resources of this project.

Nevertheless, the research team believes that a meaningful study can still be conducted. To accomplish this, the construction projects selected for evaluation must broadly represent "typical" conditions that are likely to occur throughout Wisconsin. Then, field testing (as described under Task 3) can be used to assess whether the major variables under consideration (coarse aggregate type, AEA type, concrete plant, paver type) have an important influence on the loss of air or changes in the air-void system as the concrete passes through the paver. Based on this analysis of typical concrete paving conditions, general recommendations can be developed regarding the effect of these variables on the air content. If the difference in air loss and/or the quality of the air-void system are notably different from project to project, reasons for these differences will be sought and if necessary, further evaluation recommended.

Using this approach, the research team is proposing that 12 projects be included in this study, as indicated with an "X" as shown in table 1. The darkened rows reflect the information provided in the RFP that indicated only Zignego Company is using the Erie-Strayer concrete plant and that they also use the G&Z S850 paver. The selection of 12 projects is based on available project resources and the extensive amount of field work and laboratory study required.

Table 1. Proposed experimental matrix.

Air Entraining Admixture		**Vinsol Resin**		**Non-Vinsol Resin**	
Coarse Aggregate Source		**Gravel**	**Limestone**	**Gravel**	**Limestone**
Paver	**Plant**				
G&Z S850	Rexcon		X		X
	Erie-Strayer		X		X
GHP 2600	Rexcon		X		X
	Erie-Strayer				
GHP 2800	Rexcon	X		X	
	Erie-Strayer				
Rexcon Town and Country	Rexcon	X	X	X	X
	Erie-Strayer				

The Zignego Company is predominantly located in the southeastern part of Wisconsin where limestone is the predominant aggregate source. Limestone aggregates are also far more likely to be used on the most heavily trafficked pavements in Wisconsin, which are largely located in the southern part of the state. It is assumed that Michels Paving is using a Rexcon concrete plant as well as the G&Z S850 paver, thus by setting up a *2x2* matrix in which the coarse aggregate type is fixed on limestone, comparisons can be made on the effect of concrete plant and AEA for the G&Z S850 paver. Since most pavers in Wisconsin use a Rexcon concrete plant and a Rexcon Town and Country paver, this was also seen a good opportunity to compare the effects of coarse aggregate type and AEA.

The comparisons for the Gomaco pavers focus on the impact of AEA. The GHP 2800 is used by two companies located in the northern to central parts of Wisconsin, thus the use of gravel coarse aggregate was selected for the comparison. The companies using the GHP 2600 are more centrally located and thus likely use both limestone and gravel, but it was decided to include them in testing the limestone aggregate. It is noted that the two Gomaco pavers, although differing in size and power, are fundamentally the same as far as design, and thus the manner in which concrete is placed is not expected to be significantly different. If the two Gomaco pavers are considered as a single entity, then the experiment as presented can also provide a direct comparison of the effect of aggregate type.

The design presented in Table 1 is based on the information currently available and is likely to change as additional information is obtained and candidate construction projects are identified. The development of the final experimental matrix is heavily dependent upon participation of WisDOT and the Wisconsin Concrete Pavement Association (WCPA) and its members to find projects representing the broadest number of variables possible while adhering to the project's budgetary constraints.

Task 3: Fieldwork and Laboratory Testing

This task is broken into the following three distinct subtasks reflecting three very specific activities: fieldwork at the time of construction; post-construction field sampling of hardened concrete; and laboratory testing. APTech will be responsible for the conduct of these work activities, but will be assisted by AET in the field sampling and by MTU in the laboratory testing. A summary of these activities are described in the following sections.

Subtask 3a: Fieldwork During Construction

During construction, a Wisconsin HTCP PCC Tech I certified technician from AET will be on site to test the fresh properties of the concrete and prepare cylindrical specimens (4-in by 8-in) for future laboratory analysis. The technician will coordinate all of their activities with the contractor, ensuring safety and minimal disruption to the paving operation. The fresh concrete properties to be measured are air content in accordance with AASHTO T 152, *Air Content of Freshly Mixed Concrete by the Pressure Method* and unit weight in accordance with AASHTO T 121, *Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete*. Sampling and testing of fresh concrete will be conducted on concrete placed on grade directly in front of the paver and directly behind the paver after placement. The latter item will be retrieved in the center portions of the slab to avoid edge effects and at locations away from any embedded steel. The research team recognizes that sampling of the concrete behind the paver is somewhat problematic as it requires sampling a freshly placed paving lane, disturbing the surface, and requiring extra work for the contractor to repair and finish the surface. All efforts will be made to closely coordinate these testing activities with the contractor and WisDOT field personnel to ensure smooth operations.

One full day of technician time has been allocated to each of the 12 projects. Testing will only be initiated after initial start-up and once the concrete supply and paving operation is operating smoothly. Within each project, a minimum of three sampling sites will be selected along the length of the project. Each site will be clearly located using project stationing and physical markers place just outside the immediate construction zone. In addition to the AASHTO T 152 and T 121 testing, the technician will make two cylindrical specimens (4-in diameter by 8-in length) at each site, one from concrete placed before the paver and one from concrete placed after the paver (see figure 1). Thus, for each of the 12 projects, six cylindrical specimens will be cast. These specimens will be used in the laboratory testing described in Subtask 3c. Through coordination with the contractor and/or WisDOT, the carefully labeled cylindrical specimens will be stored with QA/QC specimens collected on the project and retrieved at a later date as described under Subtask 3b.

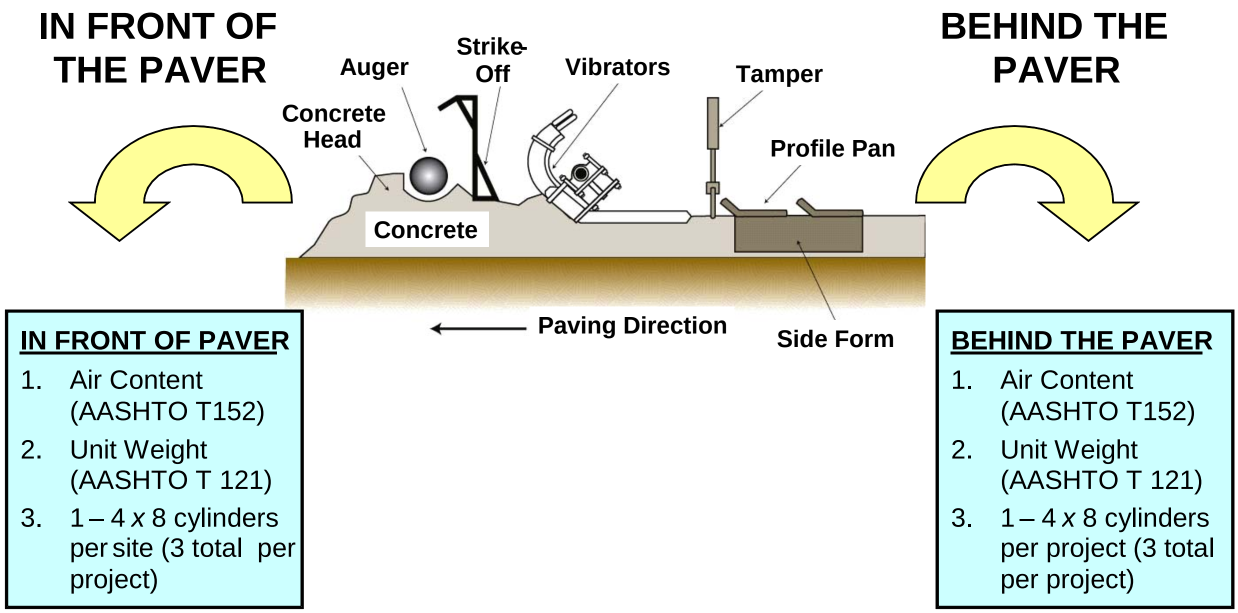


Figure 1. Fresh concrete sampling at each sampling site within a project.

Subtask 3b: Field Sampling of Hardened Concrete

It is well known that the air-void system of the hardened concrete is often affected in non-uniform ways by the paving operation, and the only way to capture this is through examination of extracted concrete specimens. At least seven days after construction and prior to opening the pavement to traffic, three cores will be extracted from each project, one from each of the three sampling sites. To minimize the impact of the coring on pavement performance, the cores will be extracted from the interior of the slab. Because the air content of hardened concrete can be adversely affected by internal vibration, if there are any signs of "vibrator trails" visible on the surface, two cores will be extracted at that sampling site, one in the vibrator trails and one between them. The cylindrical specimens and extracted cores will be delivered to MTU and tested as described in Subtask 3c.

Subtask 3c: Laboratory Testing

Table 2 summarizes the full laboratory testing matrix that can be conducted on the cast and extracted specimens from each project. As noted in subtask 3a, a total of six cylindrical cast specimens will be available from each project (two from each of the three sampling sites). Furthermore, a minimum of three extracted core specimens will be available as described in Subtask 3b. In total, there are 108 concrete specimens that would be available for testing from the 12 project sites.

It is proposed that the specimens be tested in accordance with ASTM C457, *Standard Test Method for Microscopical Determination of the Parameters of the Air-Void System in Hardened Concrete: Procedure B, the Modified Point-Count Method*. Testing, which will be supervised by Dr. Larry Sutter at Michigan Tech, will be conducted on slabbed and polished specimens using a stereo zoom optical microscope. ASTM C457 will be used to assess the characteristics of the entrained air-void system and to judge the general uniformity of the concrete. Due to the labor intensive nature of this test, ASTM C457 can only be conducted on approximately one-half of the available specimens (approximately 54 specimens). For each of the 12 projects, all three specimens from a single sampling site will be tested, resulting in 36 total tests. The remaining 18 ASTM C457 test specimens will be selected after careful consideration of the test results from the fresh concrete and hardened concrete. In addition, all efforts will be made to include additional testing to the degree that resources allow.

Table 2. Full testing matrix for cylindrical and core specimens obtained at each project site.

Test Method	Cast Cylinders Obtained During Construction		Extracted Cores
	Before Paver	After Paver	
ASTM C457	3	3	3[#]
Air-Void System Characteristics via Flatbed Scanner	3[*]	3[*]	3[*]

[#] If vibrator trails are observed, the extracted core evaluated will be from the vibrator trail.

[*] Conducted on the same polished surface as ASTM C457.

In addition to observations made in accordance with ASTM C457, the same polished surface will be evaluated using the flatbed scanner technique, which was developed at MTU under WisDOT Project 00092-03-16, for which Dr. Sutter served as PI and Dr. Van Dam served as the Co-PI. Since the completion of that project in 2007, the system has been adopted by a number of companies and universities including Purdue University and the University of Toronto, and significant interest has been expressed in commercialization of this procedure. Dr. Peterson (an advisor to this project), who is transitioning from a position at Michigan Tech to the University of Toronto, has continued to improve the system, which will allow a more thorough characterization of the size and distribution of the air throughout the depth of the concrete to better study the spatial distribution of the air voids; a critical element in understanding the impact of the paver on the air-void system. This is why it is essential that cores extracted from the pavement be analyzed and compared to cast cylinders made from concrete obtained after the paver since subtle but important spatial features in the air-void system will be thoroughly disrupted in the cast specimen as the fresh concrete is removed and re-compacted into the mold. Through the use of the flatbed scanner technique, not only will the ASTM C457 results be validated, differences that exist in the cast versus extracted air-void systems will be quantified and the importance of these differences assessed with regards to anticipated future performance.

Task 4: Data Analysis and Final Report

Under the fourth and final task, the APTech research team will analyze the results of the field and laboratory testing and develop a final report documenting the entire research effort. These activities will be performed in the following three subtasks.

Subtask 4a: Data Analysis

Dr. Van Dam will lead the data analysis work to be conducted under this subtask. Sufficient replication (there are 3 replicate sampling sites per project) exists to conduct limited statistical analyses (t-test, ANOVA, and so on) on the impact of the aggregate type, AEA, plant type, and paver type on the fresh concrete properties (air content, unit weight). Similarly, valid statistical relationships on how the independent variables affect compressive strength will also be obtainable. It is emphasized that the conclusions drawn from the statistical analyses will be applicable only to the specific conditions of the projects under study for the reasons previously stated under Task 2, but yet they will be useful in establishing the range in differences that can be expected across a broad number of projects. The air-void system parameters obtained on the hardened concrete will be useful in drawing relationships between tests conducted on fresh concrete and the resulting air-void system, as well as in determining to what extent the loss in air affects the anticipated freeze-thaw durability of the concrete. Specifically, the work will be conducted to determine the following:

- The degree of air loss observed through the paver for conditions typical in Wisconsin and whether these differences would be expected to compromise the freeze-thaw durability of the concrete.

- Whether differences observed in the air content and air-void system parameters in concrete obtained before and after the paver are dependent on the coarse aggregate type, the type of AEA, the type of concrete plant, and/or the type of paver used.
- Whether measured air-void system parameters observed in concrete extracted from the pavement is sufficiently similar to those observed is cast specimens made from fresh concrete obtained before and after the paver.
- Whether any of the various paving machines under investigation have any impact on the air-void system.
- Possible causes of any differences observed, potential methods to address these differences, and recommendations for future work to address unsolved issues.

Subtask 4b: Draft Final Report and TOC Presentation

Once the analysis is complete, a draft Final Report will be prepared and submitted to the TOC for review four months in advance of project completion. A preliminary draft outline for the final report is presented below:

- Chapter 1. Introduction
- Chapter 2. Background and Problem Statement
- Chapter 3. Field Projects and Data Collection Program
- Chapter 4. Laboratory and Data Analysis
- Chapter 5. Findings and Recommendations
- Appendix A. Annotated Bibliography

The TOC will have three months to review the draft report, culminating with a presentation of the report to the TOC one month prior to project completion. The meeting is anticipated to be held in Madison at a time mutually convenient to both the research team and members of the TOC.

Subtask 4c: Incorporate TOC Recommendations and Final Report

After the presentation and TOC review of the draft Final Report, the research team will incorporate TOC comments and prepare the project final report. Thirty-six (36) hard copies of the Final Report will be printed and delivered to WHRP by the contract end date. In addition, an electronic copy of the Final Report suitable for web-posting will also be provided to WHRP in a format of their choosing.

Expected Contribution from WisDOT Staff

WisDOT staff is expected to contribute in the following ways:

- Coordinate with research team and contractors to find and select projects that meet the objectives of the study.
- Assist in coordinating fieldwork and working with the AET technician to accommodate the cast cylindrical specimens until they can be retrieved by the research team at a later date as described in Subtask 3b.
- Provide traffic control for the coring rig if the project has been opened to traffic prior to the coring operation described in Subtask 3b.

Anticipated Research Results and Implementation Plan

Research Product

The primary product of this research study is the Final Report, which will include the comprehensive literature review, the selection process and details regarding each project, the data collected during construction and laboratory evaluation, the approach and results of the data analysis, and overall findings and recommendations. Recommended changes, if justified, will be made for WisDOT's *Standard Specifications for Highway and Structure Construction* and the applicable *Standard Special Provisions, QMP for Concrete Pavements and QMP for Ancillary Concrete.* Of specific interest is the establishment of the required range of air contents for concrete placed on grade in front of the paver that ensures it is protected against freeze-thaw damage. An assessment regarding benefits in terms of performance and cost savings will also be included in the Final Report, as will recommendations for future work.

Intended Audience

The primary intended audience for this study and the Final Report are WisDOT engineers responsible for developing and maintaining the *Standard Specifications for Highway and Structure Construction* and the applicable *Standard Special Provisions, QMP for Concrete Pavements and QMP for Ancillary Concrete.* The secondary audience includes other WisDOT and non-WisDOT engineers involved in the design and construction of concrete pavements as well as those in the contracting industry responsible for their construction. The contents of the Final Report will also likely be of interest to concrete material suppliers and equipment manufacturers.

Potential Impediments to Implementation

The largest impediment to implementation is the variability inherent in a material as complex as slipformed paving concrete. This is not a study evaluating perfectly proportioned, carefully mixed, and meticulously prepared laboratory mortar or concrete. Instead it is a study of real concrete, placed as part of real projects, and thus subject to all of the variability that is present under these conditions. As a result, within the given project resources, it is impossible to draw "statistically valid" results for all occasions for the reasons discussed under Task 2. Thus, the largest impediment to implementation would be an expectation that this study will reveal absolute truths instead of trends; something that the research team, WisDOT, and the WCPA and its members will have to work to dispel.

Implementation Activities

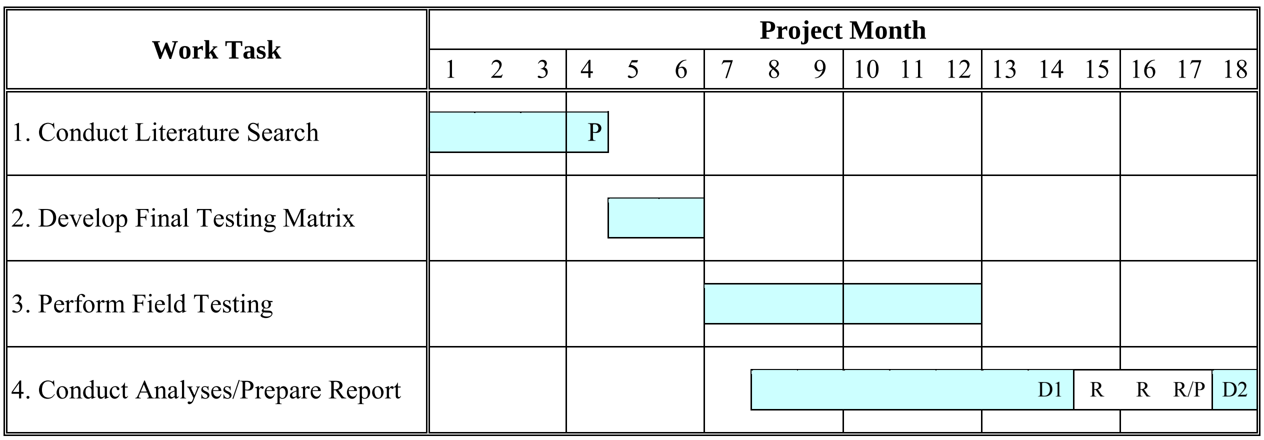
Successful implementation of this project entails making recommendations for justifiable changes in the development and maintenance of the *Standard Specifications for Highway and Structure Construction* and the applicable *Standard Special Provisions, QMP for Concrete Pavements and QMP for Ancillary Concrete.* Of specific interest is the establishment of the required range of air contents for concrete placed on grade in front of the paver that ensures that it is protected against freeze-thaw damage after paving. To facilitate this, the research team will conduct the following activities:

- Thoroughly and clearly document the research findings in the Final Report including summarizing the recommended potential changes to existing standard specifications and clearly describing benefits in terms of enhanced performance and cost savings.
- Assist WisDOT in promoting the changes by participating in technology transfer activities such as the Mid-Continent Transportation Symposium, the annul workshop of the WCPA, and the annual meeting of the Transportation Research Board.
- Work with WisDOT to create an article for a Research Brief and similar technology transfer materials.

SECTION 5. TIME REQUIREMENTS

The proposed project schedule is shown in figure 2. The proposed schedule is in keeping with the 18-month period specified in the RFP and assumes that work will begin October 1, 2010 and ends on March 31, 2012. A summary of key initiation and end dates for each task is provided below:

- Task 1 begins October 1, 2010 and ends January 31, 2011
- Task 2 begins February 1, 2011 and ends March 31, 2011 (TOC presentation)
- Task 3 begins April 1, 2011 and ends September 30, 2011
- Task 4 begins May 1, 2011 and ends Mar 31, 2012 (TOC presentation)



R = TOC Review
P = Presentation to TOC
D = Deliverable (D1=Draft Final Report; D2=Final Report)